RADIATION PHYSICS NOTE 110

Neutron Response of a Cutie Pie Ion Chamber Instrument

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I. Introduction

On February 22, 1993 a survey was conducted along the top of the AP0 vault walls to determine how the gradient of the gamma versus neutron dose changes with location. During beam on target conditions, it is known that a mixed field of gamma and neutron radiation are present at the vault. To separate the gamma dose component from the neutron dose component, it was expected to subtract the integrated cutie pie gamma dose reading from the integrated chipmunk gamma and neutron dose readings. The data from that survey indicated that the cutie pie response to the mixed gamma-neutron field was as high or higher than the chipmunk response, contrary to the expected result that the chipmunk response would be higher. Therefore, it was not possible to distinguish the gamma dose from the neutron dose.[1]

The possibility that there were low energy photons affecting the cutie pie, which has a superior low energy photon response compared to the chipmunk, was eliminated by testing the cutie pie with about an inch thick stack of aluminum sheets between the chamber and the source. There was no difference in the cutie pie's integrated response to the source at AP0.

The effect of neutrons on a cutie pie instrument had been previously investigated by Fred Krueger .[2] This R.P. note will serve to describe the mixed gamma neutron radiation conditions under which a cutie pie instrument should be used, and to provide data on the cutie pie's relative response to the average neutron energy of an Americium:Beryllium source.

II. Test Procedure

Tests of a cutie pie's response to neutrons were conducted in the mezzanine of the Radiation Physics Calibration Facility (RPCF) on April 23 and April 26, 1993 . A Fermilab designed ion chamber constructed to measure both gamma and neutron doses (chipmunk) was used to provide comparative readings for the cutie pie readings. Each count (output pulse) reported on the chipmunk scaler represented 2.5 μrem to the chipmunk chamber, and its output pulse quality factor was set at x1 to obtain results that would be directly comparable to the cutie pie readings. The chipmunk chamber axis was always oriented perpendicular to the radiation flux, that is the long side of the yellow box facing the source. The cutie pie chamber axis was oriented perpendicular or parallel to the flux, and the plastic end cap was attached and detached to observe any effects the chamber orientation and the end cap had on the cutie pie's response. The chipmunk has the same wall material in all directions, therefore its orientation was not varied.

A Nuclear-Chicago model 2592 cutie pie (no. 11) and chipmunk no. 50 were first tested to verify that they responded to within 10 % of a calculated true gamma dose rate. They were placed in the gamma field (6.05 mR/hr at 2 meters) of a Cobalt-60 source (Fermilab source serial no. 60-4.3-2).

Then the instruments were tested for neutron response. The instruments were placed into the mixed gamma neutron field from an Americium:Beryllium (Am:Be) source (Fermilab source serial no. 241-7.2-1). The Am:Be source gamma output was 0.654 mR/hr at 1 meter with a lead sleeve over the source, and the neutron output was 2.94 mrad/hr at 1 meter.[3]

III. Results and Discussion

Table 1 shows that the normalized Co-60 gamma responses of the chipmunk and cutie pie were 1.1 and 1.0 respectively, which were within 10% of the true dose rate. This test confirmed that the instruments responded within acceptable limits to a gamma source.

Table 2 shows the data for the cutie pie and chipmunk responses to the Am:Be mixed field. It is assumed that the normalized gamma response of the cutie pie is 1.0. Subtracting out the Am:Be gamma dose rate of 0.654 mR/hr from the total reading, then dividing by the Am:Be neutron dose rate of 2.94 mrad/hr is the "Apparent Response to Neutrons" factor. The mean dose rate reading given by the cutie pie instrument was 1.90 mR/hr, which was for both the instantaneous and integrated dose measurement modes 2.91 times higher than the actual gamma dose rate of 0.654 mR/hr from the Am:Be source. The results also indicate that there was an increased response of 34% to 44% when the plastic beta shield end cap was attached, indicating a moderating effect on the neutrons entering the chamber. Since the actual gamma dose rate from the Am:Be source was about 18% of the total Am:Be dose rate from both gammas and neutrons, the cutie pie responded almost 3 times higher than expected in the Am:Be mixed field.

The response of the cutie pie to the Am:Be neutrons, of which the average neutron energy is 4.4 MeV, appears to fit a curve generated from previous test data of its response to other neutron sources with average energies ranging from 0.4 MeV to 4.1 MeV. Figure 1 shows a graph of the response of the cutie pie to several neutron sources, including the Am:Be source from this test. The graph indicates that the cutie pie instruments began to respond at a neutron energy threshold of about 0.4 MeV. The best fit to the curve appears to be a polynomial fit, with a correlation coefficient of 0.997. The next best fit appears to be a linear fit, with a correlation coefficient of 0.970, and the logarithmic fit was the poorest with a correlation coefficient of 0.824. These are displayed on figure 1.

The cutie pie readings are reported in units of mR/hr for both the Co-60 gamma dose rate and the Am:Be mixed field dose rate. Since the units of mR/hr apply only to photons in air, the mR/hr readings given by the cutie pie instrument for the mixed field are technically incorrect because of the neutron component. However, the dose readings recorded in the table are shown exactly as reported by the instrument.

IV. Conclusion

The cutie pie instruments responded significantly to neutrons with energies ranging from about 0.4 MeV to 4.4 MeV. If neutrons of 0.4 MeV or greater energy are known or suspected of being present, a cutie pie should be used in conjunction with a "neutron only" detector that confirms that the neutron component of the mixed field is insignificant compared to the photon component.

REFERENCES

(1) National Bureau of Standards Handbook 63, Protection Against Neutron Radiation Up to 30 Million Electron Volts, U.S. Department of Commerce, November 22, 1957, p. 21.

(2) Fred Krueger, Determining the Fast Neutron Energy Response Characteristics of Fermilab Instrumentation, Fermilab Radiation Physics Note 86, June 1990, Revised 4/2/91.

(3) Fred Krueger, Calibration of Radioactive Sources Used by Fermilab Safety Section for Instrument Calibration and Characterization, Fermilab Radiation Physics Note 83, Revision 2, October 23, 1990.

Source Identification	Actual 1 Meter Exp. Rates	Instrument	Distance	Operating Mode	Integrated Run Time	Actual Dose Rate from Source	Instrument Reading	Scale	Time and Scale Adjusted Instrument Reading (Total Response)	Response to Gamma Only *	Apparent Response to Neutrons ***	Comment

Table 1

60-4.3-2 (Co-60 only)	24.2 mR/hr	Chipmunk #50	2 meters	Integrated	3.0 min	6.05 mR/hr	130 counts **	n/a	6.4 mrem/hr	1.1	n/a	Chamber axis perpendicular
		Cutie Pie #11	2 meters	Integrated	6.8 min	6.05 mR/hr	0.07 mR †	x10	6.2 mR/hr	1.0	n/a	Chamber axis parallel to flux, cap on

Table 2

241-7.2-1 (Am:Be only)	0.654 mR/hr gamma, 2.94 mrad/hr neutron	Chipmunk #50	1 meter	Integrated	6.0 min	3.6 mrad/hr	150 counts	n/a	3.6 mrad/hr	1.0	n/a	Chamber axis perpendicular
		Cutie Pie #11	1 meter	Rate	n/a	3.6 mrad/hr	0.18 (avg.)†† mR/hr	x10	1.8 mR/hr †††	1.0	0.39	Chamber axis parallel to flux, cap on
		Cutie Pie #11	1 meter	Rate	n/a	3.6 mrad/hr	0.15 (avg.) mR/hr	x10	1.5 mR/hr	1.0	0.29	Chamber axis parallel to flux, cap off
		Cutie Pie #11	1 meter	Rate	n/a	3.6 mrad/hr	0.20 (avg.) mR/hr	x10	2.0 mR/hr	1.0	0.46	Chamber axis perpendicular to flux, cap on
		Cutie Pie #11	1 meter	Integrated	11.0 min	3.6 mrad/hr	0.04 mR	x10	2.2 mR/hr	1.0	0.52	Chamber axis parallel to flux, cap on
		Cutie Pie #11	1 meter	Integrated	10.8 min	3.6 mrad/hr	0.04 mR	x10	2.2 mR/hr	1.0	0.53	Chamber axis perpendicular to flux, cap on
		Cutie Pie #11	1 meter	Integrated	14.1 min	3.6 mrad/hr	0.04 mR	x10	1.7 mR/hr	1.0	0.36	Chamber axis parallel to flux, cap off

* - Cutie pie normalized response to gamma only dose from Am:Be source is assumed to be 1.0 in all cases

** -Chipmunk background was 14 counts in 15 minutes = 0.93 cpm

*** - (total response - 0.654)/2.94

† -Cutie Pie background is insignificant (0.003 mrem/15 minutes)

†† -Ten Rate readings were taken by glancing at the meter face ten times, then an average of the ten rates was taken.

††† NOTE: The unit of mR/hr is technically incorrect for the mixed field dose measured by the cutie pie.

Neutron Energy Response of the Cutie Pie Instrument

Log Fit y = 7.15e-2 + 0.28*LOG(x) R^2 = 0.824

Linear Fit y = - 4.37e-2 + 7.58e-2x R^2 = 0.970

Polynomial Fit y = - 4.856e-2 + 0.13x - 5.14e-2x^2 + 8.93e-3x^3 R^2 = 0.997

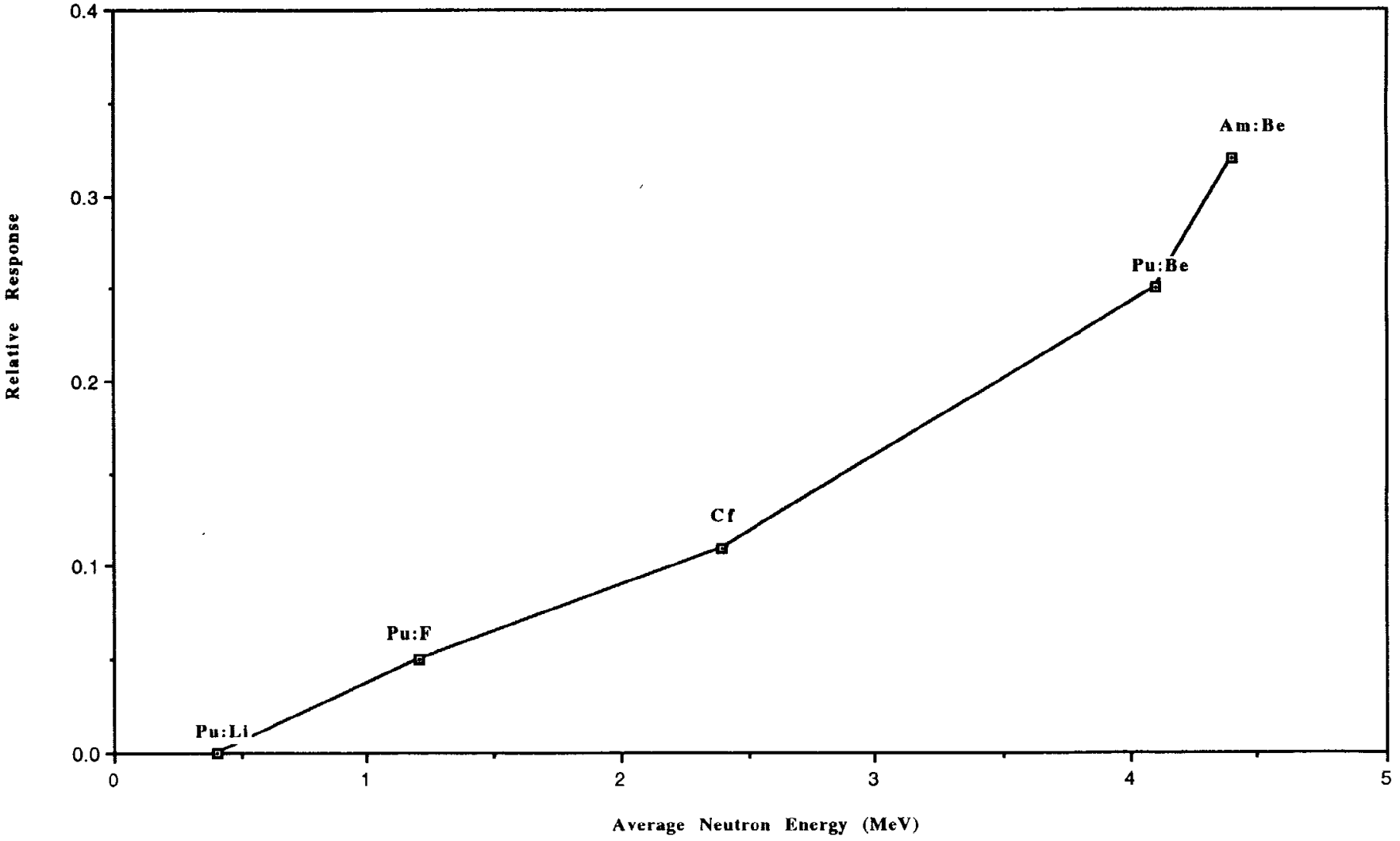

Figure 1